The effect of rotation on the gluon condensate

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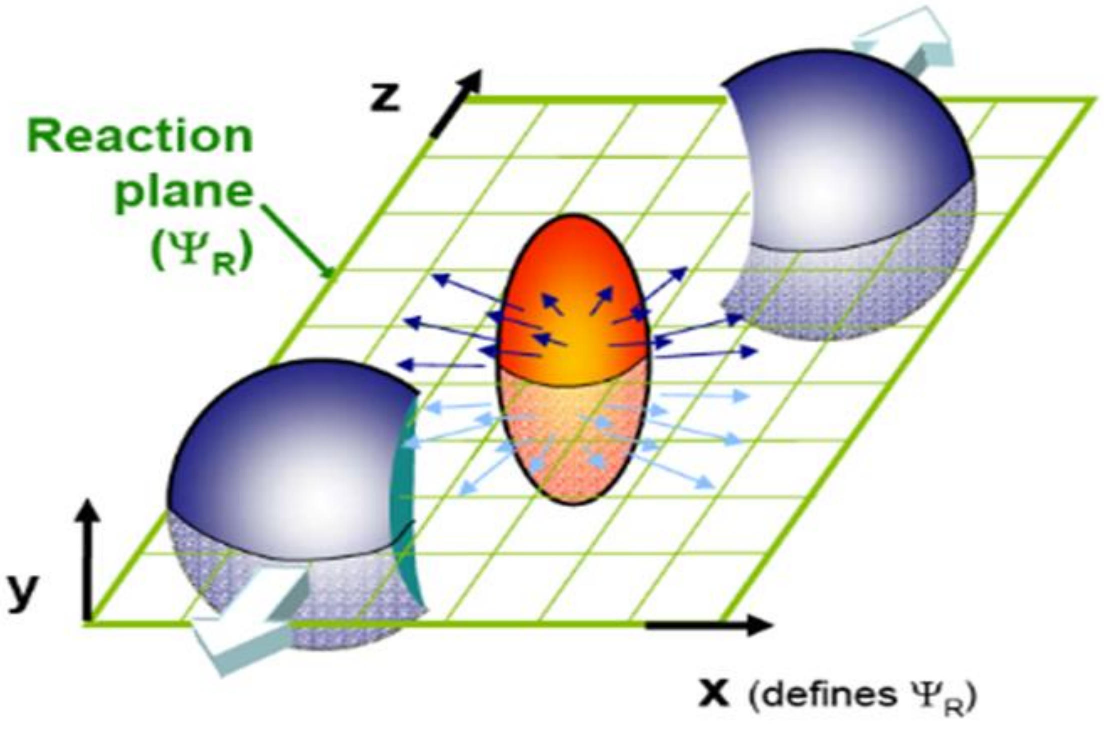
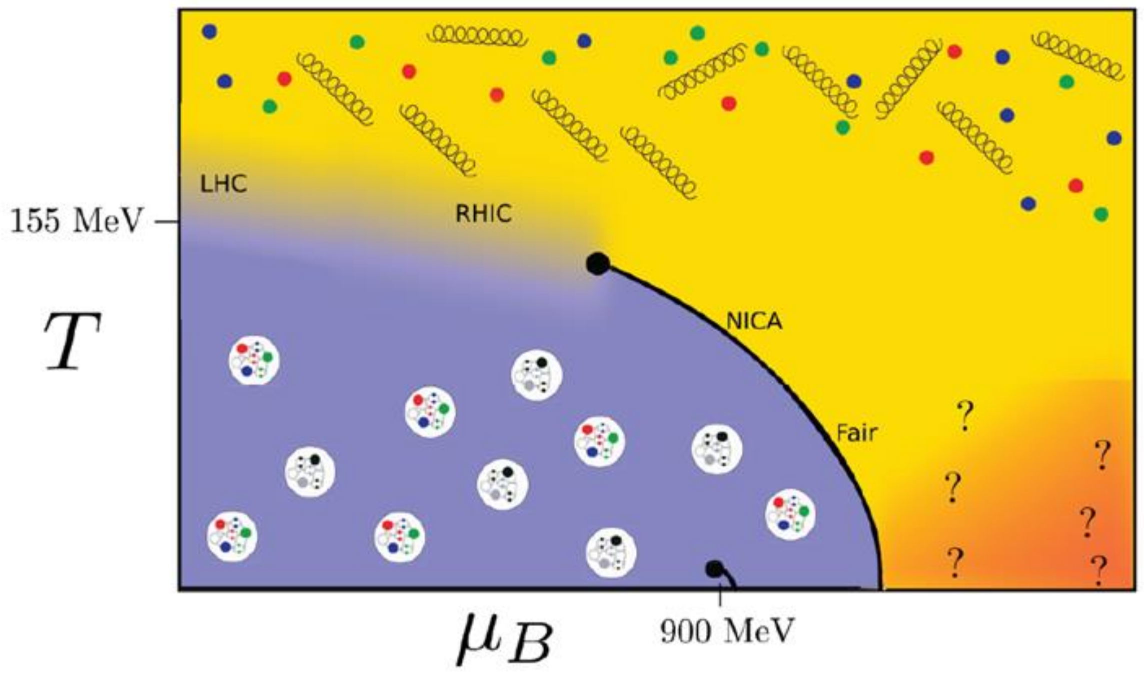




1. Z. T. Liang and X. N. Wang, Phys. Rev. Lett. 94, 102301 (2005)
2.W. T. Deng and X. G. Huang, Phys. Rev. C **93**, no. 6, 064907 (2016)
3. Y. Jiang, Z.W. Lin, and J. Liao, Phys. Rev. C 94, 044910 (2016)
4. L. G. Pang, H. Petersen, Q. Wang, and X. N. Wang, Phys.Rev. Lett. 117, 192301 (2016)
……

AdS/CFT duality is proposed by Maldacena in 1997.

hep-th/9711200 , cited 19075

$\mathcal{N}=4$ Super Yang-Mills (SYM) theory with gauge group $SU(N)$ and Yang-Mills coupling constant g_{YM} is dynamically equivalent to type IIB superstring theory with string length $l_s=\sqrt{\alpha'}$ and coupling constant g_s on $AdS_5\times S^5$ with radius of curvature L and N units of $F_{(5)}$ flux on S^5.

Not strictly speaking, there may be a relationship between the Strongly-coupled 4d gauge theory and 5d AdS spacetime.

$$R_{\mu\nu}-\frac{1}{2}R\,g_{\mu\nu}+\underbrace{\Lambda}_{\text{宇宙常数}}g_{\mu\nu}=\frac{8\pi G}{c^4}T_{\mu\nu}$$

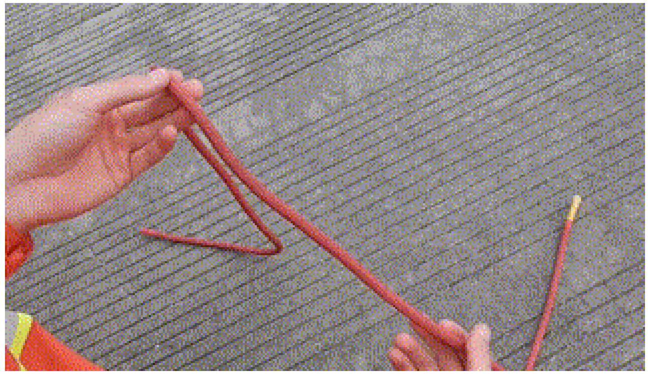
Top-down and Bottom-up model

(1) D3-D7 model, D4/D8 model…

(2) Einstein-Maxwell-Dilaton Model, V-QCD model….

AdS/QCD, holographic QCD, Gauge/gravity duality…

According to the holographic principle, a D-dimensional field theory is dual to the (D + 1)-dimensional gravitational theory, and the extra dimensions can be understood as renormalization group flows.



Background: $$S=\frac{1}{16\pi G_5}\int d^5x\sqrt{-g}\left[R-\frac{h(\phi)}{4}F^2-\frac{1}{2}\partial_\mu\phi\partial^\mu\phi-V(\phi)\right]$$

ϕ 伸缩子 dilaton

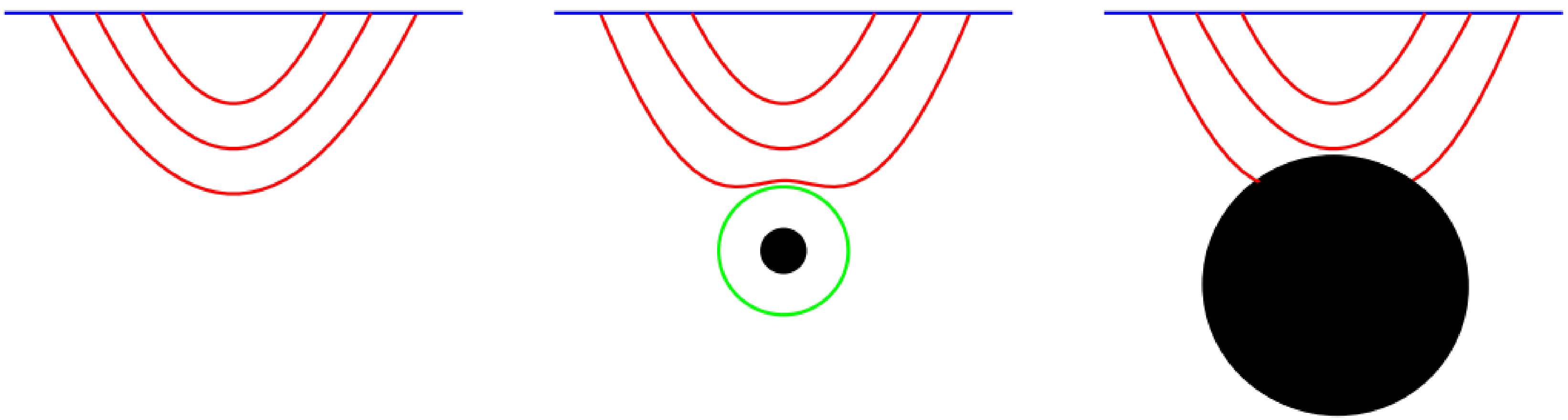
$$ds^2=\frac{L^2e^{2A_e(z)}}{z^2}\left[-G(z)dt^2+\frac{1}{G(z)}dz^2+d\vec{x}^2\right]$$

Probe: $$I=\int d^5x e^{-\Phi(z)}\sqrt{g}\left\{-|DX|^2+3|X|^2-\frac{1}{4g_5^2}\left(F_L^2+F_R^2\right)\right\}$$

Linear Confinement and AdS/QCD, Andreas Karch, Emanuel Katz, Dam T. Son, Mikhail A. Stephanov, hep-ph/0602229

Dynamical holographic QCD model for glueball and light meson spectra,
Danning Li and Mei Huang, arXiv:1303.6929

Confinement/deconfinement phase transition = Hawking page phase transition

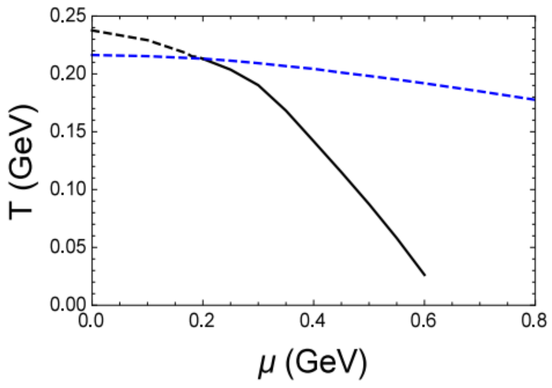


(a) (b) (c)

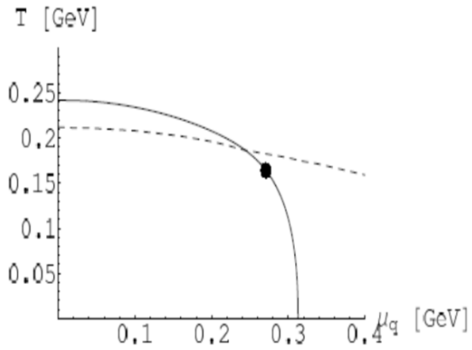
black hole horizon/Temperature, black hole charge/chemical potential

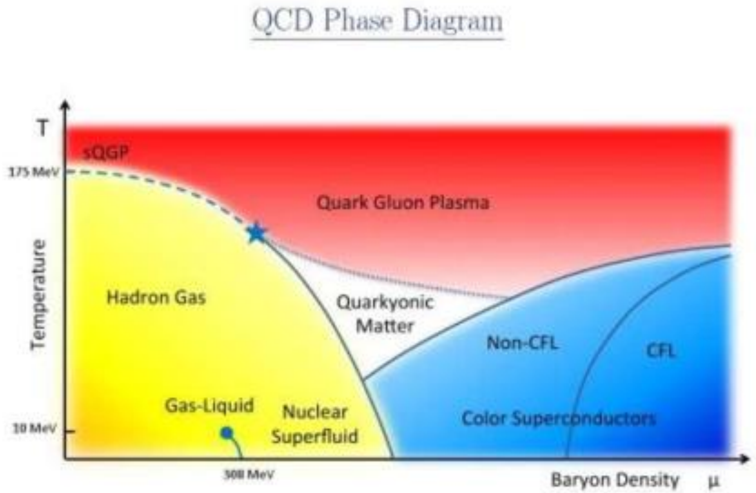
Quarkyonic phase from quenched dynamical holographic QCD model, JHEP 03 (2020) 073
Xun Chen, Danning Li, Defu Hou and Mei Huang

全息模型



PNJL模型





Possible quarkyonic matter phase.

Quarkyonic = quark + baryon

Angular Momentum in QGP Holography, Brett McInnes, *Nucl.Phys.B* 887 (2014)

Consider the case of rotating, electrically charged AdS black holes with topologically spherical event horizons. Here the angular velocity is constant (both in space and in time) on the event horizon but also on the boundary, so there is no differential motion there: the boundary is rotating, not shearing.

$$g(\mathrm{AdSKN}) = -\frac{\Delta_r}{\rho^2}\left[\,\mathrm{d}t - \frac{a}{\Xi}\sin^2\theta\,\mathrm{d}\phi\right]^2 + \frac{\rho^2}{\Delta_r}\,\mathrm{d}r^2 + \frac{\rho^2}{\Delta_\theta}\mathrm{d}\theta^2 + \frac{\sin^2\theta\,\Delta_\theta}{\rho^2}\left[a\,\mathrm{d}t - \frac{r^2+a^2}{\Xi}\mathrm{d}\phi\right]^2$$

where

$$\begin{aligned}
\rho^2 &= r^2 + a^2\cos^2\theta \\
\Delta_r &= \left(r^2+a^2\right)\left(1+\frac{r^2}{L^2}\right) - 2\Xi^2 Mr + \frac{\Xi^2 Q^2}{4\pi} \\
\Delta_\theta &= 1 - \frac{a^2}{L^2}\cos^2\theta \\
\Xi &= 1 - \frac{a^2}{L^2},
\end{aligned}$$

Non-spherical event horizons Black brane

Rotating hairy black holes in arbitrary dimensions, arXiv:1707.03483

A Cardy-like formula for rotating black holes with planar horizon. arXiv: 1702.02416

$$I = \int d^n x \sqrt{-g} \left[\frac{R}{2\kappa} - \frac{1}{2} g^{\mu\nu} \partial_\mu \Phi \partial_\nu \Phi - \frac{\xi}{2} R \Phi^2 - V(\Phi) \right]$$

$$ds^2 = \quad -N^2(r) f(r) dt^2 + \frac{dr^2}{f(r)} + H(r)\left(d\phi + N^\phi(r) dt\right)^2 + r^2 d\Sigma^2$$

$$t \to \frac{1}{\sqrt{1-(\omega l)^2}} \left(t + \omega l^2 \theta\right), \phi \to \frac{1}{\sqrt{1-(\omega l)^2}} (\theta + \omega t)$$

Gluodynamics and deconfinement phase transition under rotation from holography
JHEP 07 (2021) 132
Xun Chen, Lin Zhang, Danning Li, Defu Hou, and Mei Huang

$$ds^2 = -N(z)dt^2 + \frac{H(z)dz^2}{G(z)} + R(z)(d\theta + P(z)dt)^2 + H(z)\sum_{i=1}^{2} dx_i^2$$

The Hawking temperature can be calculated from the surface gravity κ as

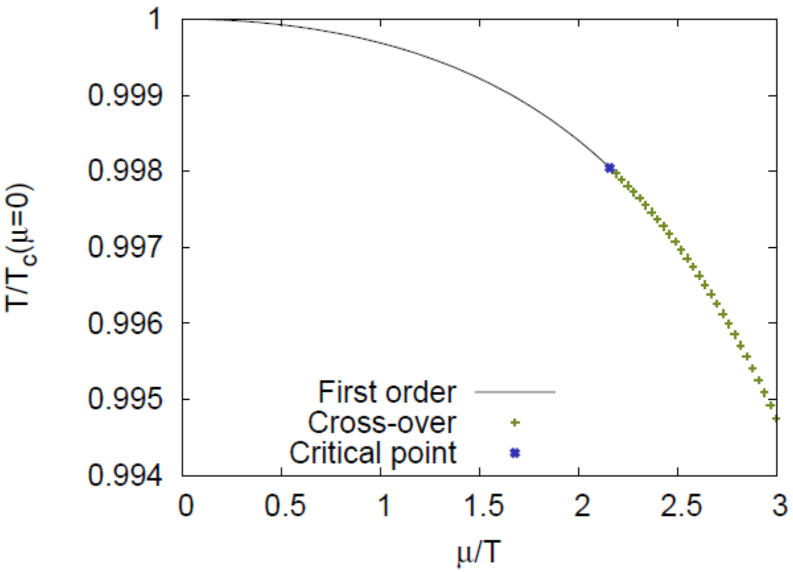
$$T = \left|\frac{\kappa}{2\pi}\right| = \left|\frac{\lim\limits_{z\to z_h} -\frac{1}{2}\sqrt{\frac{g^{11}}{-\hat{g}_{00}}}\hat{g}_{00,1}}{2\pi}\right|.$$

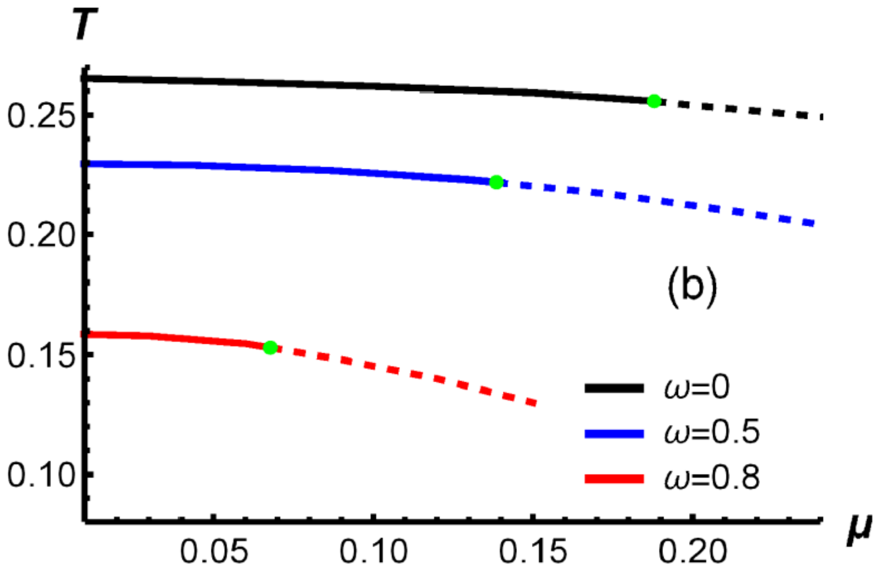
the quark chemical potential under rotation can be defined as

$$\mu = A_\mu \chi^\mu\Big|_{z=z_h} - A_\mu \chi^\mu\Big|_{z=0}.$$

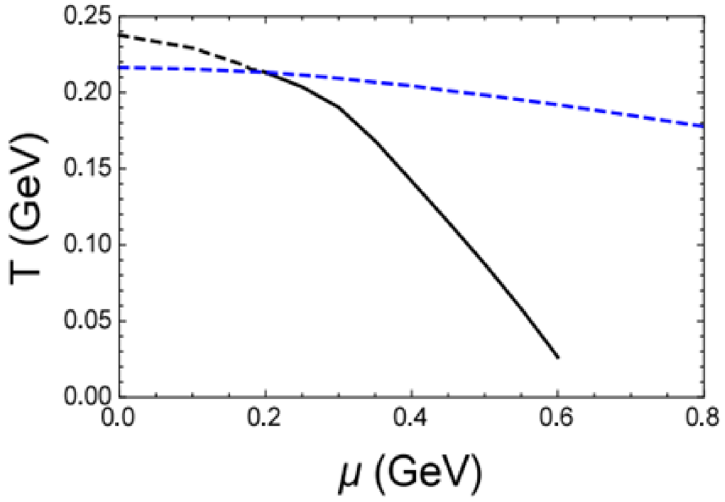
arXiv:1111.4953

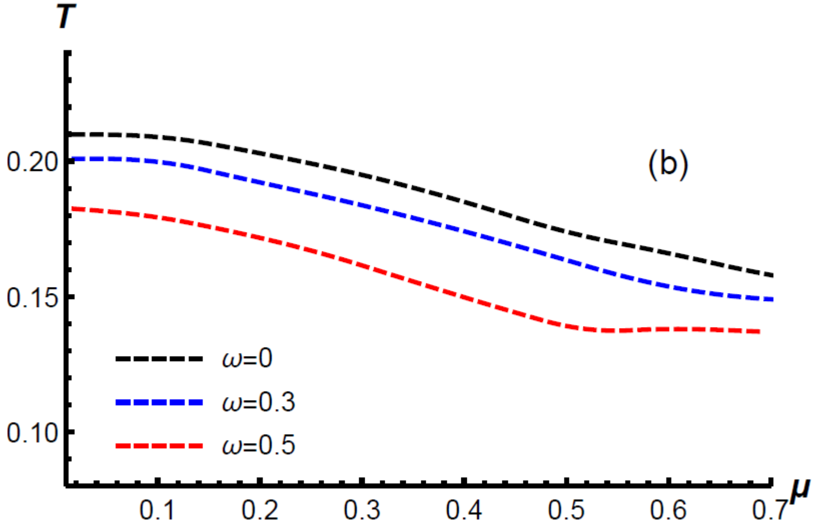
Heavy quark





Two flavor

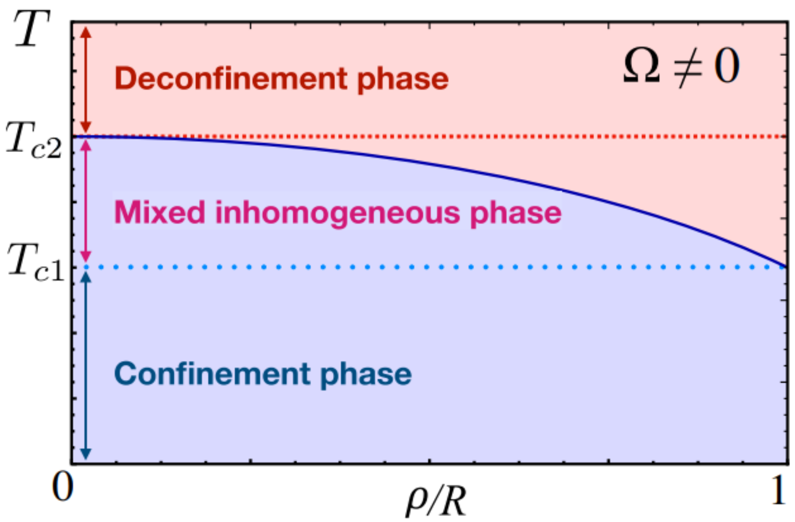




Inhomogeneous confining-deconfining phases in rotating plasmas

PHYSICAL REVIEW D 103, 054027 (2021) M. N. Chernodub

Compact electrodynamics (called also compact QED or cQED for shortness) which is a toy model that possesses the confinement property and, at the same time,can be treated analytically.



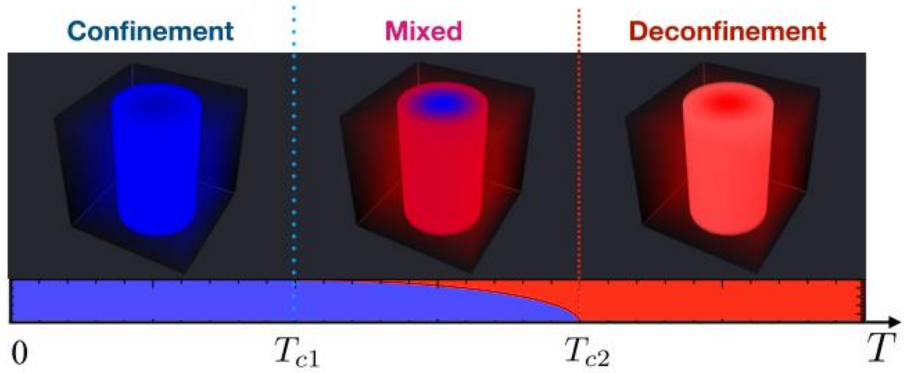


FIG. 7. Illustration of the confining, mixed, and deconfining phases of the uniformly rotating system at finite temperature.

Tolman-Ehrenfest law

$$T(\boldsymbol{x})\sqrt{g_{00}(\boldsymbol{x})} = T_0,$$

The effectivetemperature

$$\boldsymbol{T_\Omega(\rho) = T(0)\left(1 + \frac{1}{2}\rho^2\Omega^2 + O(\Omega^4)\right)}$$

Generation of vortices and stabilization of vortex lattices in holographic superfluids

Xin Li, Yu Tian, Hongbao Zhang. J. High Energ. Phys. 2002, 104 (2020)arXiv:1904.05497

Schwarzschild-AdS balck brane
$$ds^2 = \frac{L^2}{z^2}\left(-f(z)dt^2 + \frac{1}{f(z)}dz^2 + dr^2 + r^2 d\theta^2\right)$$

$$S = \int_M \sqrt{-g}d^4x \left[\frac{1}{2\kappa^2}\left(R + \frac{6}{L^2}\right) - \frac{1}{e^2}\left(\frac{1}{4}F^2 + |D\Psi|^2 + m^2|\Psi|^2\right)\right]$$

A simple way to solve the model is considering the probe limit.

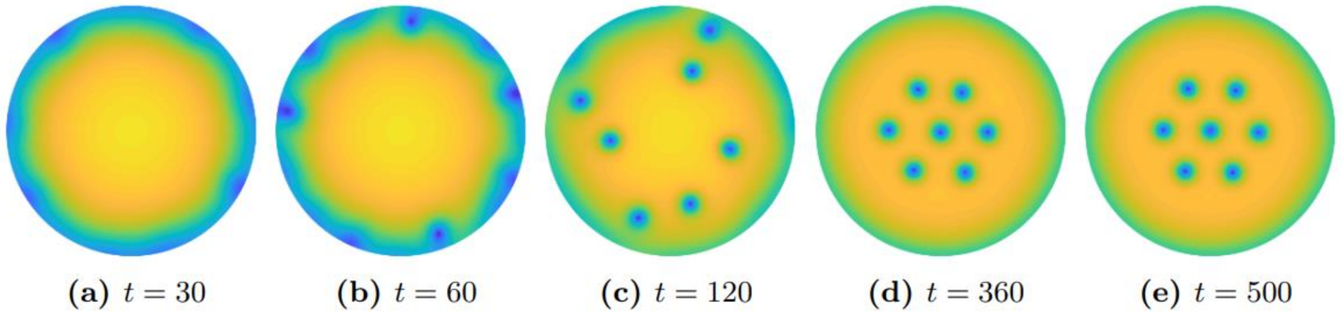


Figure 4. Condensates as functions of space coordinates at different time when $\Omega = 0.168$. In this plot, 7 vortices appear, which form the simplest triangular lattice.

Inhomogeneous chiral condensation under rotation in the holographic QCD
Phys.Rev.D 106 (2022) 10, 106002 • e-Print: 2208.05668

Yidian Chen, Danning Li, Mei Huang

$$ds^2 = \frac{L^2}{z^2}\left[-f(z)dt^2 + \frac{dz^2}{f(z)} + dr^2 + r^2 d\theta^2 + dx_3^2\right]$$

$$S_M = -\int d^5 x\sqrt{-g}e^{-\Phi(z)}\left\{\mathrm{Tr}\left[\left(D^M X\right)^\dagger (D_M X)(+|V_X|X)\right] + \frac{1}{4}F_{MN}F^{MN}\right\}$$

According to the AdS /CFT dictionary, the UV asymptotic behavior of the scalar field χ has the form $m_q \zeta z + \cdots + \frac{\sigma}{\zeta} z^3$ with quark mass m_q, quark condensation σ and the normalization constant $\zeta = \frac{\sqrt{3}}{2\pi}$

As a result of the rotation, the probe action involves a new gauge field A_M, which is dual to the non-zero current operator $\mathcal{O}^\mu = \langle \bar{q}\gamma^\mu q \rangle$ induced by the rotation, besides the complex scalar field X.

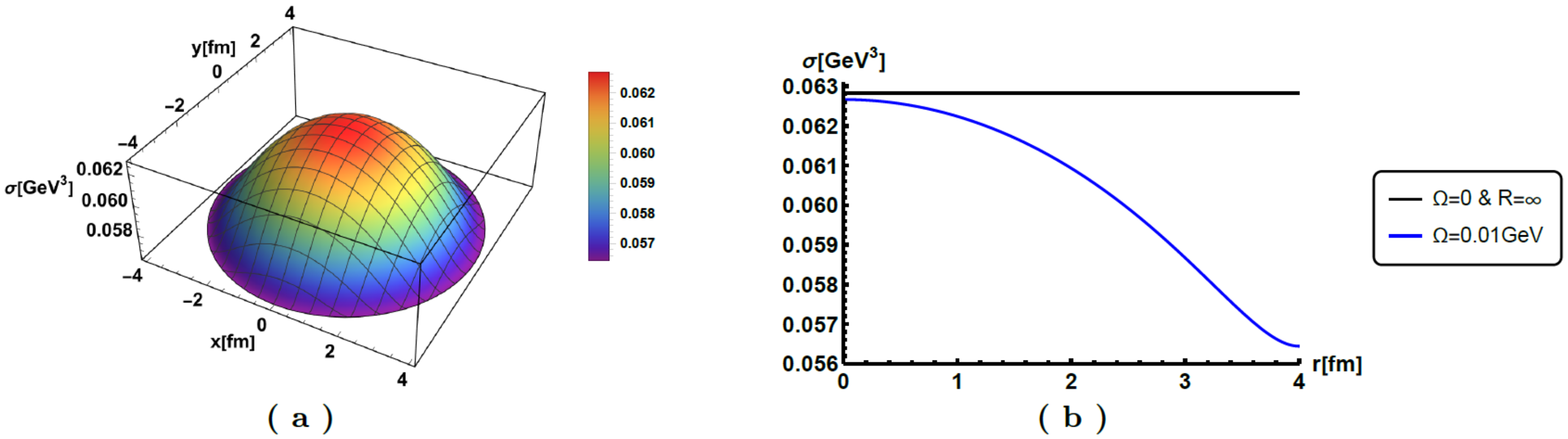


Figure 2. 3D and 2D plots of chiral condensation as a function of radial r at $T = 170\text{MeV}$ and $\Omega = 0.01$ GeV with NBC and $(m_q, v_3, v_4) = (0, -3, 8)$. In Fig.(b), the black line indicates the value of condensation at the same temperature without rotation and finite size.

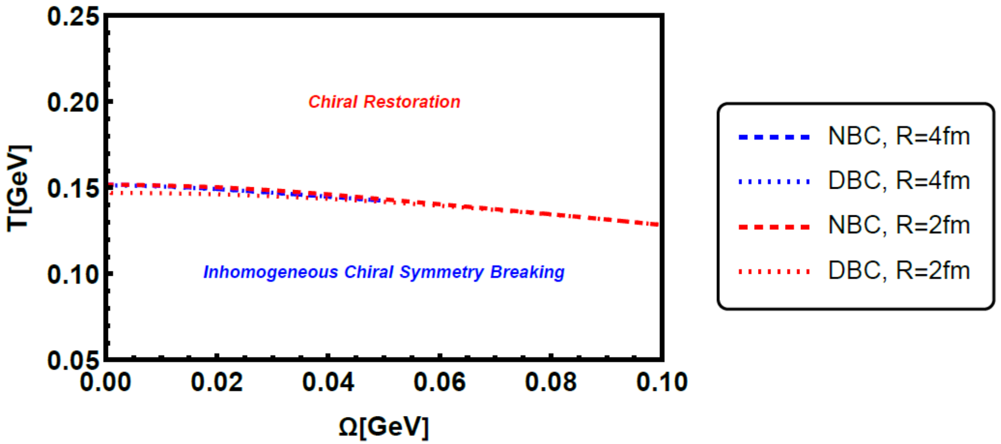


Figure 13. The $T - \Omega$ phase diagram at fixed radius R is shown in the figure. Here, the red and blue lines correspond to radii of $R = 2$ fm and 4 fm, respectively, and the dashed and dotted lines represent NBC and DBC, respectively.

Holographic gluon condensate with finite rotation and size (in preparation)
Xun Chen, Yidian Chen, Danning Li, Mei Huang.

$$S = -\frac{e^{-h(z)}}{2}\int d^4x dz\sqrt{-g}\left(\partial_\mu\phi\partial^\mu\phi + V(\phi)\right),$$

$$ds^2 = \frac{L^2}{z^2}\left[-f(z)dt^2 + \frac{dz^2}{f(z)} + dr^2 + r^2 d\theta^2 + dx_3^2\right]$$

According to an AdS/CFT prescription, the solution of classical equation of motion for a scalar field ϕ corresponding to an operator O has the following form near the 4D boundary $z \to 0$,

$$\phi(x,z) \to z^{4-\Delta}\left[\phi_0(x) + \mathcal{O}\left(z^2\right)\right] + z^{\Delta}\left[\frac{\langle O(x)\rangle}{2\Delta - 4} + \mathcal{O}\left(z^2\right)\right]$$

where $\phi_0(x)$ acts as a source for $O(x)$ and $\langle O(x)\rangle$ denotes the corresponding condensate

Fix the parameters by lattice input

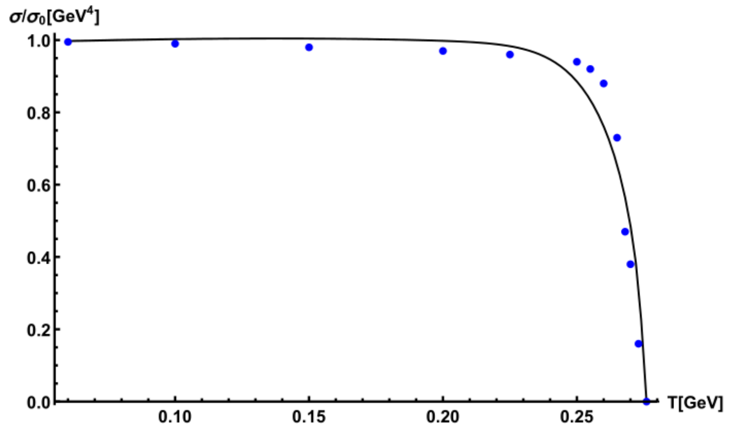


FIG. 2. Scaled dimension-4 gluon condensate as a function of temperature. The black line is the results of holographic model. The blue dots are the results of lattice QCD.

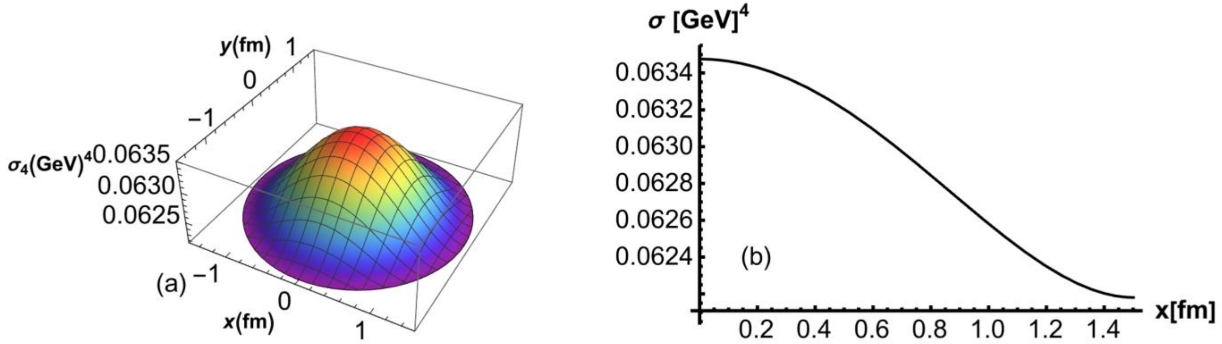
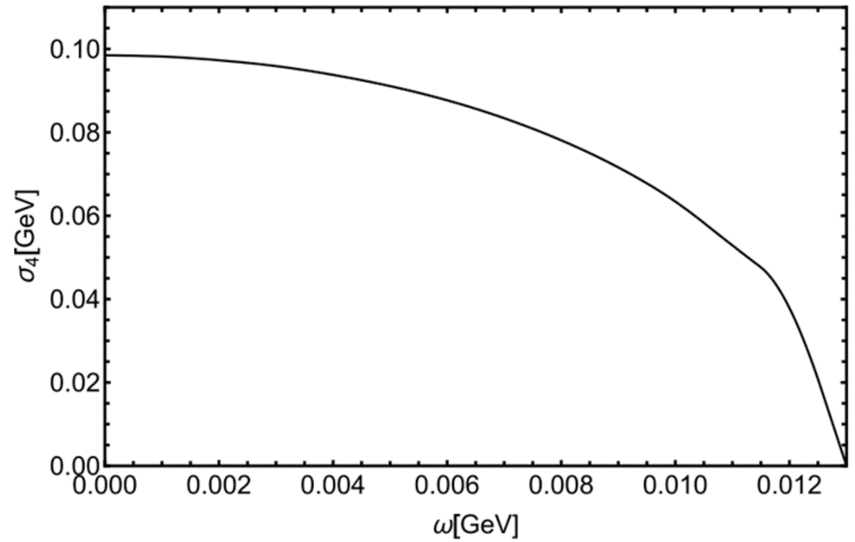


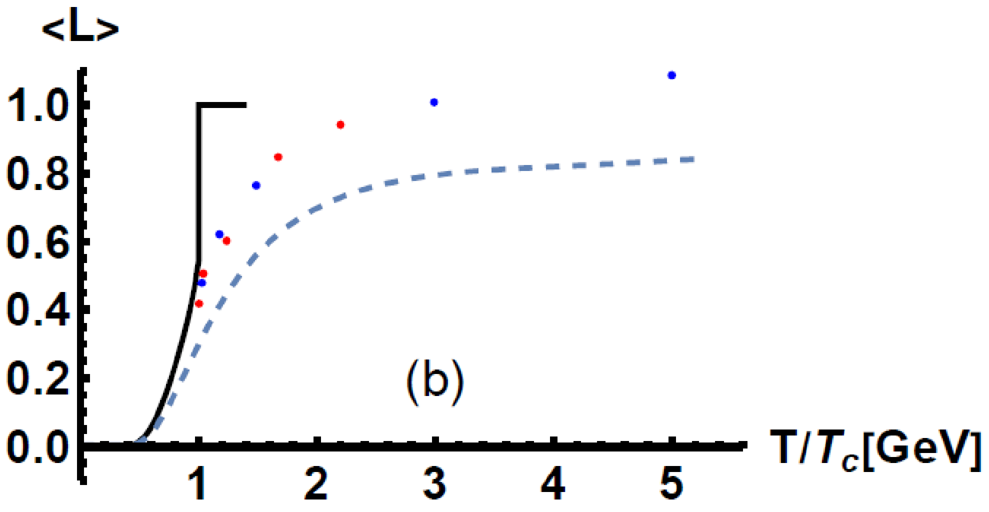
FIG. 3. (a) Dimension-4 gluon condensate as a function of x and y in the 3D plot. (b) Dimension-4 gluon condensate as a function of x in the 2D plot. The temperature is fixed as $T = 0.1$GeV, angular velocity is fixed as $\omega = 0.01$GeV and the system size is fixed as $R = 1.5$fm.

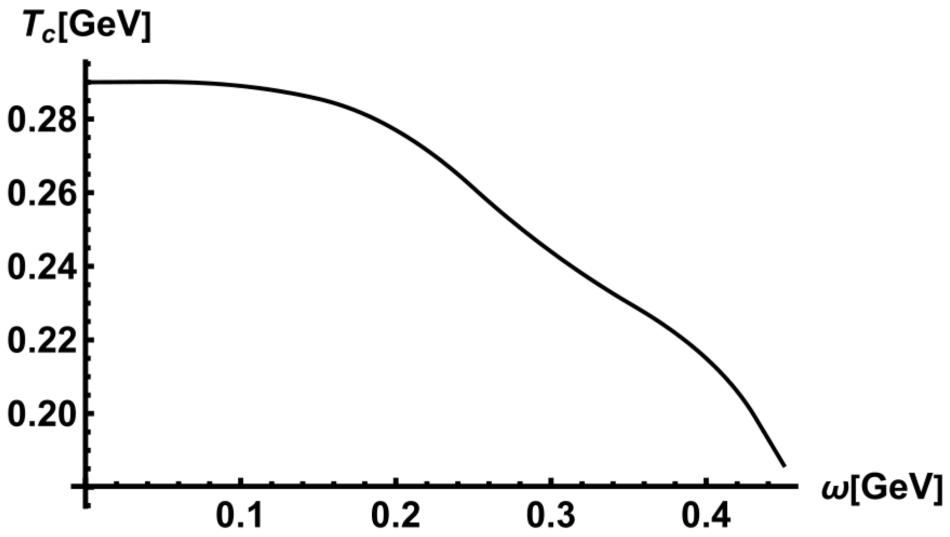


Polyakov loop expectation value is associated with the electric dimension-2 gluon condensate by the following relation[1]:

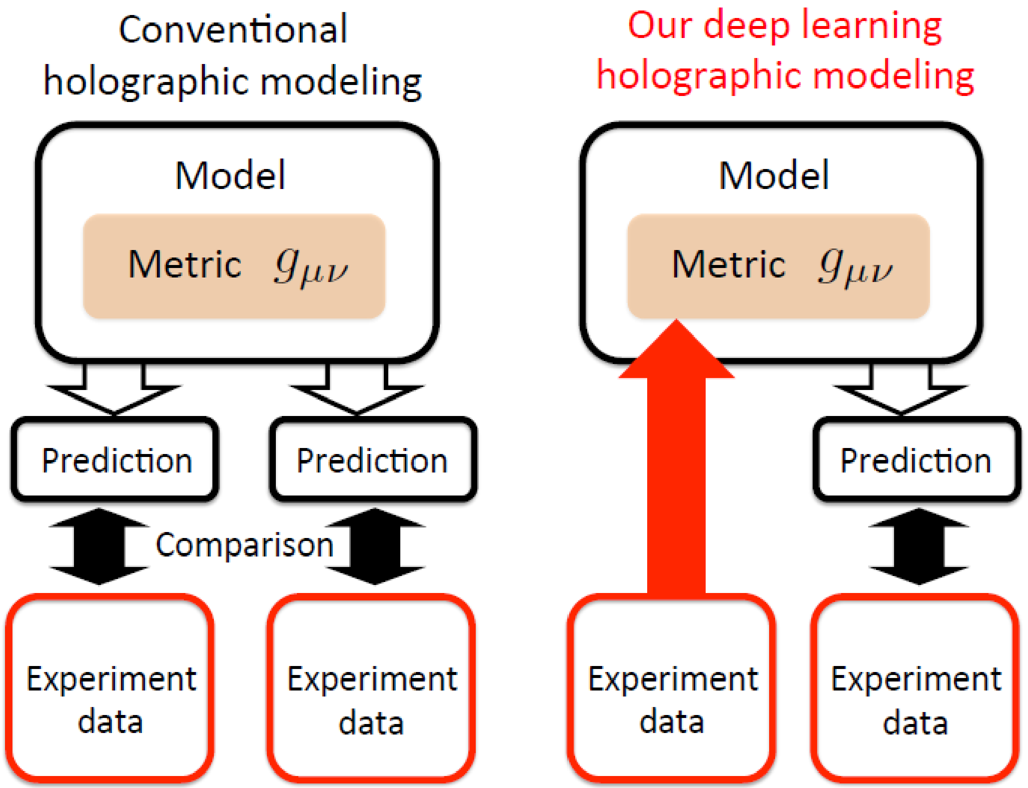
$$< L >= \exp\left[-\frac{g^2 < A_4^2 >}{4N_c T^2}\right]$$

1. Fukun Xu, Mei Huang, Electric and magnetic screenings of gluons in a model with dimension-2 gluon condensate, *Chin.Phys.C* 37 (2013) 014103. e-Print: 1111.5152.





Holographic QCD phase transition with machine learning **(in preparation)**
Xun Chen, Mei Huang.

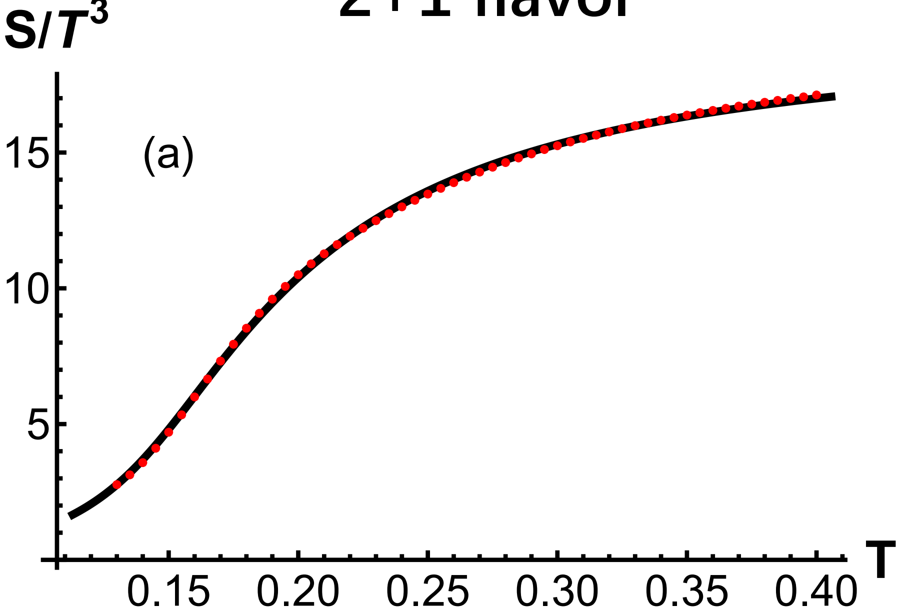


$$A(z) = d\ln\left(az^2 + 1\right) + d\ln(bz^4 + 1)$$

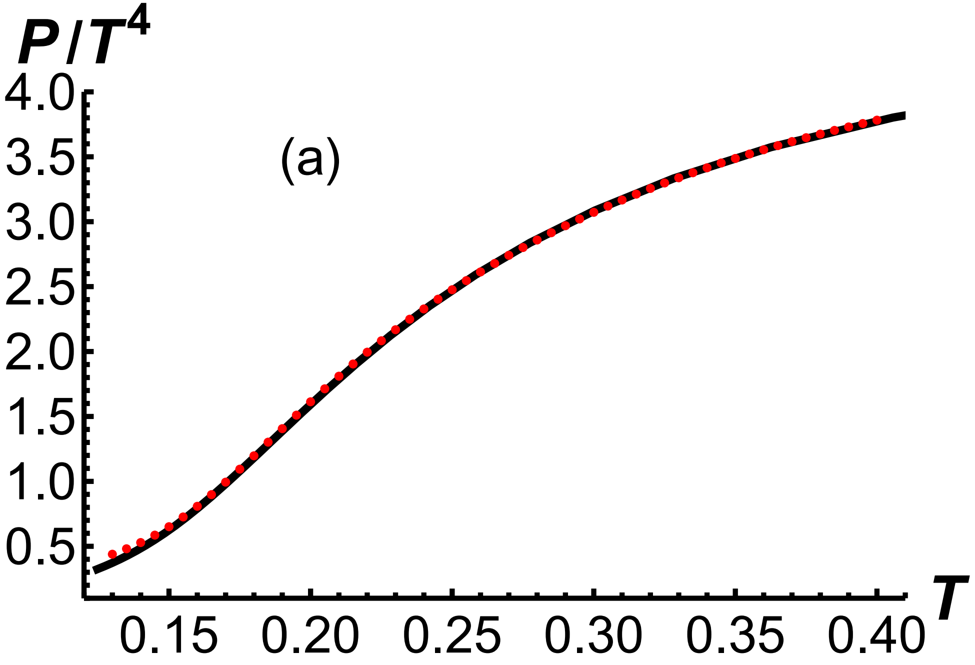
$$f = e^{cz^2 - A(z)}$$

Deep Learning and Holographic QCD, *Phys.Rev.D* 98 (2018) 10, 106014

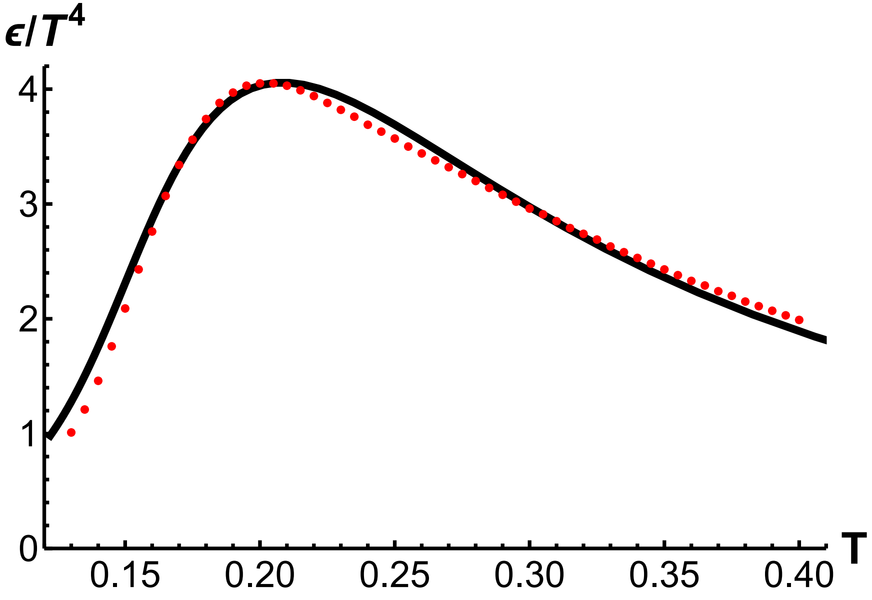
2+1 flavor



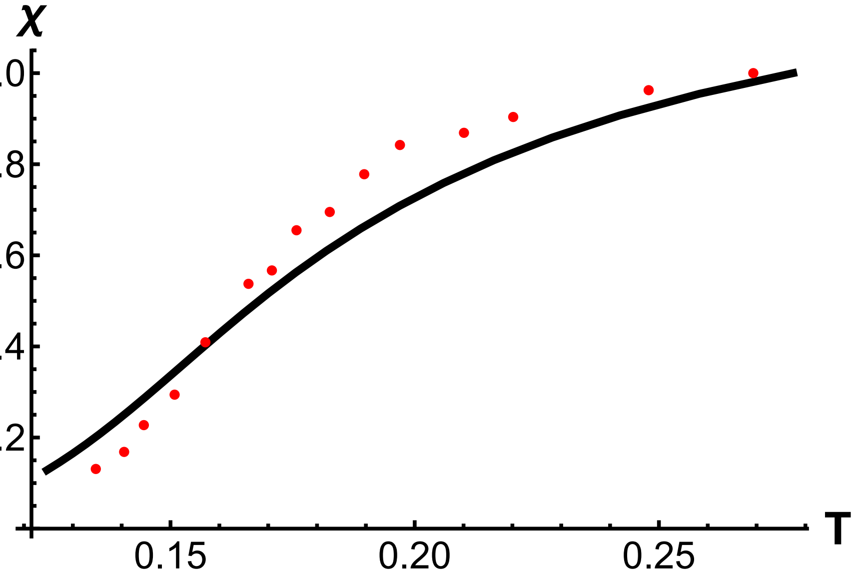
S/T^3
(a)
15
10
5
0.15 0.20 0.25 0.30 0.35 0.40
T



P/T^4
(a)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.15 0.20 0.25 0.30 0.35 0.40
T

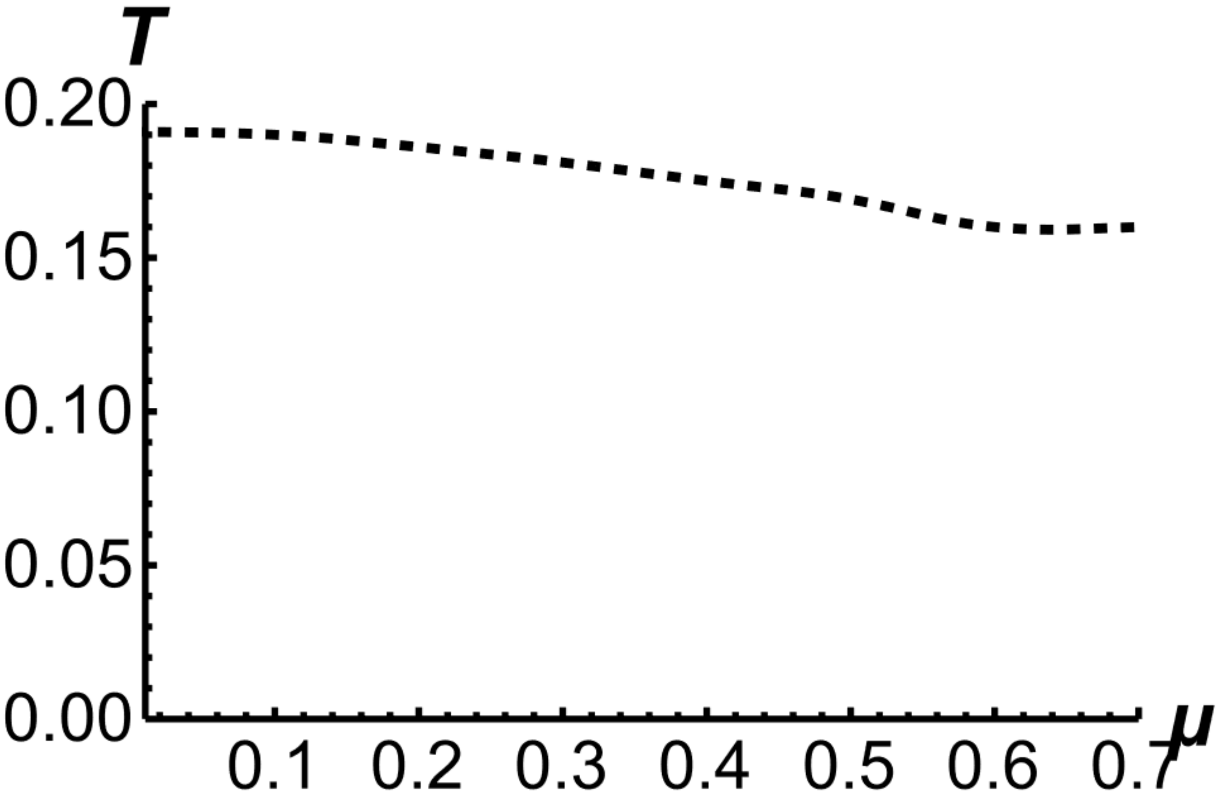


ϵ/T^4
4
3
2
1
0
0.15 0.20 0.25 0.30 0.35 0.40
T

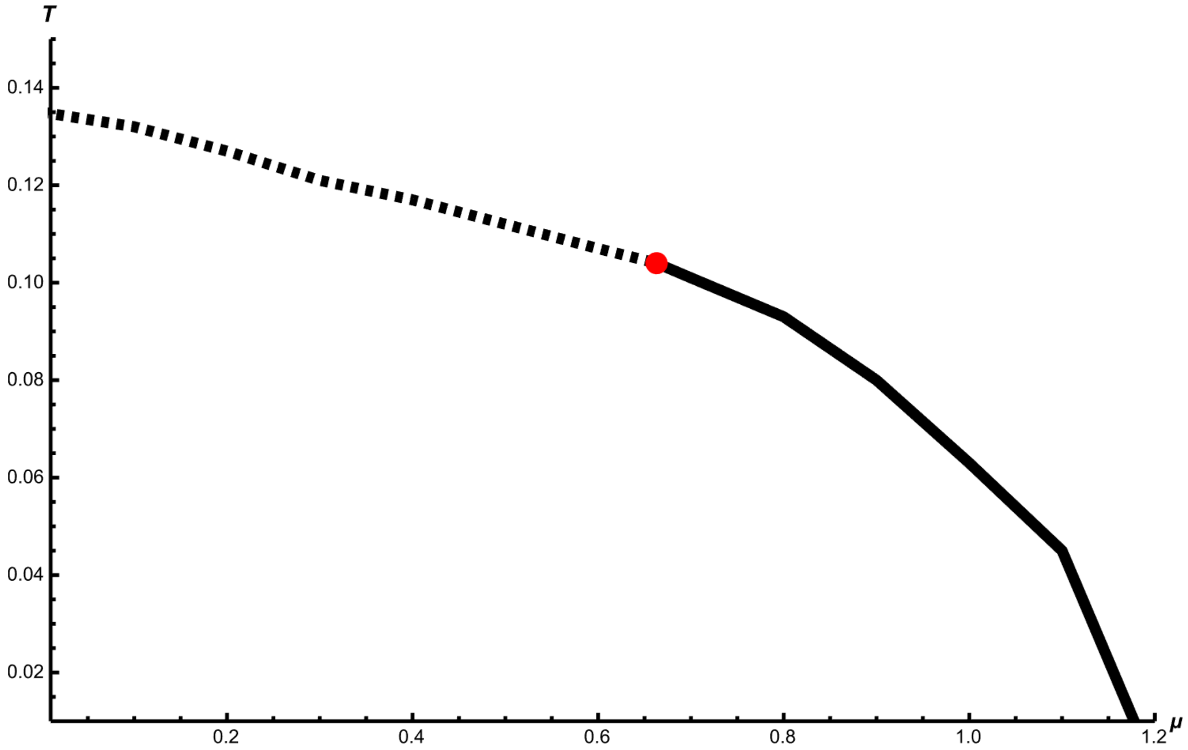


χ
1.0
0.8
0.6
0.4
0.2
0.15 0.20 0.25
T

2 flavor

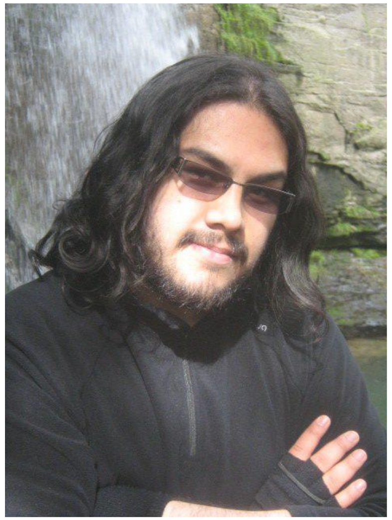


2+1 flavor



团队成员

Fujita Mitsutoshi



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谢谢大家，欢迎给与指导！